Tracts 1786 - 1.

[Extracted from the American Journal of the Medical Sciences for January 1867.]

ON THE

DETECTION AND MEASUREMENT OF ASTIGMATISM.

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(WITH FIVE WOOD-CUTS.)

Astigmatism (from α privative, and στίγμα, a point), a name proposed by Dr. Whewell to designate the visual defect dependent on a difference in the refractive power of the eye in different meridians, has been long recognized as an occasional cause of imperfect vision. The conclusive demonstrations of Dr. Young (*Philosophical Transactions*, 1801) and of Mr. Airy (*Transactions of the Cambridge Philosophical Society*, 1827 and 1849) completed the history of astigmatism as a mathematical problem, and discovered the optical means necessary for its correction; but it is to Donders, pursuing the line of ophthalmometrical research opened by Kramer and Helmholz, that we are indebted for the demonstration of its anatomical characters and the importance of its pathological relations. Far from being a rare or exceptional phenomenon, Donders has shown that astigmatism exists in an appreciable degree in almost every eye, and in its lower grades must be accepted as a normal condition, while in its higher or pathological degrees ($\frac{1}{40}$ or upwards) he has detected one of the most frequent and important of the refractive anomalies to which the eye is subject. Astigmatism may occur either alone or in connection with any of the refractive or accommodative anomalies; it may exist in one eye only, or in both eyes; and it may be symmetrical or unsymmetrical, equal or unequal, in the two eyes.

The different relations which astigmatism may bear to the refractive condition of the eye have been expressed by Donders in the form of several useful symbols, which are now very generally adopted, for the sake of brevity and precision. Astigmatism is expressed by As. Positive or myopic astigmatism in one meridian only, the other meridian being emmetropic, is Am. Negative or hypermetropic astigmatism in one meridian is Ah. Positive astigmatism in one meridian, combined with negative astigmatism in the other meridian, is written Ahm or Amh, according as the hypermetropic or myopic element predominates. Positive astigmatism in both meridians may be considered as myopia combined with myopic astigmatism, and is written M+Am. So, also, negative astigmatism in both meridians is expressed by H+Ah

These distinctions are important, and help to explain why astigmatism has so long escaped detection as a common visual defect. Thus Am, which is a partial myopia, is felt as a material disturbing influence in distant vision, but is generally mistaken for simple myopia. Ah and H + Ah, although impairing the distinctness of vision, may be so masked by strong accommodative efforts as to escape detection by any of the ordinary test-objects, and the same is true of Am and M + Am when modified, as is too often the case, by the injudicious use of concave glasses. In Ah or H + Ah the eye is in a state of continually varying accommodative tension, as well in viewing distant as near objects, and is therefore, I believe, especially liable to asthenopia from weariness of the accommodative organs. In Am or M + Am the same unrest of the accommodative organs may render reading or other fine work excessively fatiguing; while, for distant vision, the conversion of Am into Ah, by concave glasses, secures only a partial improvement in the distinctness of objects, at the cost of incessant accommodative effort. Thus, the adoption of concave glasses in Am, and still more in M + Am, is often attended with such a marked degree of asthenopia as to lead to their speedy abandonment; but when this does not occur, or when the asthenopia has been overcome by persistent use of the glasses, it is soon discovered that, after all, the improvement in vision is less than it at first appeared to be, and farther aid is sought in a stronger pair. Meanwhile, the habit of completely relaxing the accommodation in distant vision is neglected, and the apparent myopia from this cause seems to confirm the indication for the adoption of stronger glasses, and thus actual myopia is artificially induced, or, if already existing, is needlessly aggravated.[1]

The disturbing influence of the negative forms of astigmatism, Ah and H + Ah, is generally first noticed after the accommodative function has lost the extreme range which belongs to it in the earlier years of childhood. These disturbances are first detected in near vision, as in reading, and may take the form either of asthenopia, or of premature presbyopia, which is often mistaken for amblyopia. In such cases the adoption of proper convex glasses will restore to the eye whatever visual acuteness it may have originally possessed; but the full visual improvement of which the eye is capable, and especially the absolute repose which is so necessary to the asthenopic eye, can only be obtained by the use of cylindrical glasses, combined, if necessary, with spherical surfaces suited to any existing degree of ametropia or presbyopia.

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[1] That this danger of induced myopia from the injudicious use of concave glasses by astigmatic persons is a real one, I infer from the very large proportion of myopes wearing glasses, who, upon proper examination, prove to be astigmatic in a very marked degree ($\frac{1}{30}$ or upwards). This would almost appear, from my own observation, to be the rule rather than the exception, and I cannot resist the conclusion that many of these myopes were originally only astigmatic, and that their myopia is in a great degree due to the ill-advised adoption of concave glasses. I believe that it is in the highest degree imperative, in treating a case of incipient or progressive myopia, to make a careful examination of both eyes for astigmatism, and, if found, to correct it. I hope at a future time to have something more to say upon this subject.

The characteristic effects of astigmatism in modifying the distinctness of retinal images, may be very simply demonstrated by means of a convex spherico-cylindrical lens, made by combining a plano or double convex lens with a convex cylindrical lens of equal focus. Such a lens has no proper focus for parallel rays, but it may be said to have two approximate foci corresponding respectively to the meridians of greatest and least curvature. At the nearer of these approximate foci, the image of a point of light received upon a screen, takes the form, not of a point, but of a line corresponding in direction to the axis of the cylinder, upon which the cylindrical surface is ground. At the farther focus a similar linear image is formed, but at a right angle to the first. Between the two foci no distinct image can be obtained, but only a rounded spot of diffused light, which will appear of a more or less elongated shape, according as it approaches either of the foci. If, instead of the point of light, we observe the image of an elongated object, such as a window bar, we shall obtain a well-defined image at one or the other of the foci, according as the bar corresponds in direction with one or the other of the two linear images of the point of light. At intermediate distances and angles no distinct image is formed.

The analysis of the visual phenomena of astigmatism would be as simple as in the case of the spherico-cylindrical lens were it not for the disturbing influence of the accommodation. In Am and M+Am this is, under certain conditions, true. At the far point of distinct vision, corresponding to the meridian of least refraction, the retinal images will actually conform in character with those observed in the case of the lens, and the only effect of accommodative efforts will be to throw the whole image out of focus, and so render vision still more defective. In Ah, on the other hand, the eye when at rest is in a condition to receive a distinct image of lines lying in the direction of the meridian of least refraction, while a certain effort at accommodation will suffice to change the adjustment of the eye so as to adapt it to lines lying in the direction of the other principal meridian. With intermediate degrees of accommodative effort, however, vision will be less distinct than at these two points, and the eye will, therefore, either instinctively adapt itself to one or the other of them, according to the peculiar conformation of the object under inspection, or else will unconsciously oscillate from one to the other, so as to make out in succession as many features as possible. So also in H+Ah there will be one degree of accommodative effort suited to one meridian of most distinct vision, and another degree suited to the other meridian, and the unconscious changes from one to the other, and back again, will most effectually confound any attempts to estimate the degree and direction of the astigmatism. Similar disturbing acts of accommodation take place in near vision, also, in all cases in which the two near points fall near enough together to admit of this change from one to the other. Thus, in reading, the eye instinctively adapts itself to the refractive power of the meridian, which admits of, on the whole, the most distinct and easiest recognition of the letters, but as soon as any doubt arises as to any particular sign or letter, an involuntary effort shifts the adjustment to the other focus, with, perhaps, an equally unconscious rotary movement of the head or of the book. So long as the range and region of accommodation suffice for these adjustments, so long may the phenomena of astigmatism be overlooked in the mass of confused and seemingly inconsistent experiences, and this explains how it is that so many cases of astigmatism are first detected when the eyes have become presbyopic, either from the approach of old age, or in consequence of original hypermetropia.

The phenomena of astigmatism are also frequently masked by a difference in the refractive power of the two eyes. Thus, with a difference in refractive power equal, or about equal, in degree to the astigmatism, it may happen that, by the use of both eyes, lines corresponding in direction to the two principal meridians will be distinctly seen, while lines intermediate in direction appear confused.[1] So far, binocular vision may be an improvement over the use of one eye, but, unfortunately, the effect of the combination upon the image of a point is to transform it, not into a simple line, as either eye would do by itself, but into a cross. Here, then, the simultaneous use of the two eyes may materially detract from the distinctness of vision.

Similar anomalous results may be observed where the refractive power of the two eyes is equal, but when the direction of the principal meridians varies. In the greatest number of cases of astigmatism, especially in the lower grades, the direction of the principal meridians undoubtedly approximates to the vertical and horizontal, but generally with a very appreciable variation. This variation is oftenest symmetrical, but the exceptions are exceedingly common.

In the investigation of refractive anomalies of the eye, it is of the first importance to eliminate the disturbing influence of accommodative efforts, for in this way only can we in any case be certain to detect even a pretty high grade of astigmatism. This is best attained by the employment of rather large test-diagrams, hung upon the wall at a distance of fifteen or twenty feet, so as to avoid the necessity of sensible convergence of the visual axes. In the negative forms of astigmatism (Ah and H + Ah) the eye must be fitted with a convex lens of sufficient power to neutralize, or perhaps a little more than neutralize, the hypermetropia, so as to convert the case, for the purposes of the examination, into one of Am or M + Am. If we have to examine a myope for astigmatism, we must test his vision either without glasses, or with such concave glasses as shall leave a little of the myopia uncorrected. The disturbance caused by accommodative efforts may also be overcome by the use of optometers based upon that of Dr. Young (*Philosophical Transactions*, 1801). Such an optometer, with a stelliform diagram, has been employed by A. Burow (*Archiv für Ophthalmologie*, IX. Band, Berlin, 1863); and more recently, with many improvements, by E. Javal (*Annales d'Oculistique*, tome lv., 1866).

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[1] In this fact lies an important chance of error in the use of the common test diagrams, constructed of vertical and horizontal sets of lines.

2dly. In view of the great difference which often exists in the refractive phenomena in the two eyes, the examination should always be conducted with one eye at a time. This is greatly facilitated by the use of a little screen hung by a pivot to the centre of a pair of trial spectacle-frames; when the screen is placed parallel to the visual axes, the test object is visible to both eyes; to exclude the vision of either, it is only necessary to turn the screen through a small angle to the right or left.

3dly. The method employed must be competent to the detection of astigmatism, in whatever direction the principal meridians may happen to lie.

4thly. It must afford the means of accurately measuring the direction of the principal meridians.

5thly. It must provide for the accurate measurement of the refractive power in the two principal meridians, or the difference in refractive power in these meridians.

Lastly. Having corrected, by experimental glasses, any ametropia or astigmatism which may have been discovered, the state of the accommodative function should be investigated. The eyes should then be tried together, or, if the difference in the two eyes is too great for useful binocular vision, it may be of advantage to correct them singly, one for near and the other for distant vision, thus keeping both eyes in habitual use, and conferring the incidental benefit of distinct vision both of near and of distant objects without changing or removing the glasses.

The astigmatic tests hitherto most employed are the illuminated point or line, and the card of vertical and horizontal lines. The former test is made by punching a hole or slit in a sheet of thin metal, which is hung in a window or before a lamp. The vertical and horizontal lines, in sets of three or more, are ruled or printed in black ink on white paper. In using the illuminated point, the test of astigmatism is in the apparent elongation of the point in the direction of one of the principal meridians. With the vertical and horizontal lines it is a question of the relative distinctness of the two sets.

These tests, as ordinarily employed, are not very satisfactory in practice. The changes in the apparent form of the bright dot are not very conspicuous, and it is not always easy for the person examined to give an accurate and intelligible statement of what he really sees. The vertical and horizontal lines would answer well enough, if they always coincided in direction with the meridians of greatest and least refraction; but this is rather the exception than the rule. Both tests are subject to certain fallacies, and they give but a rough indication of the direction of the principal meridians. They are both, however, susceptible of improvement, the line tests by simply increasing their number and giving to them various degrees of inclination, the dot tests by multiplying the dots and arranging them in rows of different degrees of inclination.

The tests which I employ are made up of radiating lines, or of radiating rows of dots. The line tests, sixty in number, are printed in black or colored ink on a white card, and are arranged as radii of a circle. These lines are severally distinguished by a graduation around the circumference of the circle, like the hours and minutes on the dial of a clock (Fig. 1). Each line is equal in thickness to the lines employed by Snellen in the construction of No. XX. of his test-types, and is designed to be distinctly seen by an average eye at a distance of twenty feet. A second diagram is constructed of twelve sets of triple radiating lines printed upon a circular card, and corresponding to the twelve hours of the clock (Fig. 2). Upon a third card, also circular, a single set of three parallel lines is printed. The second and third cards are arranged to turn upon a pivot fixed in the

Fig. 1.

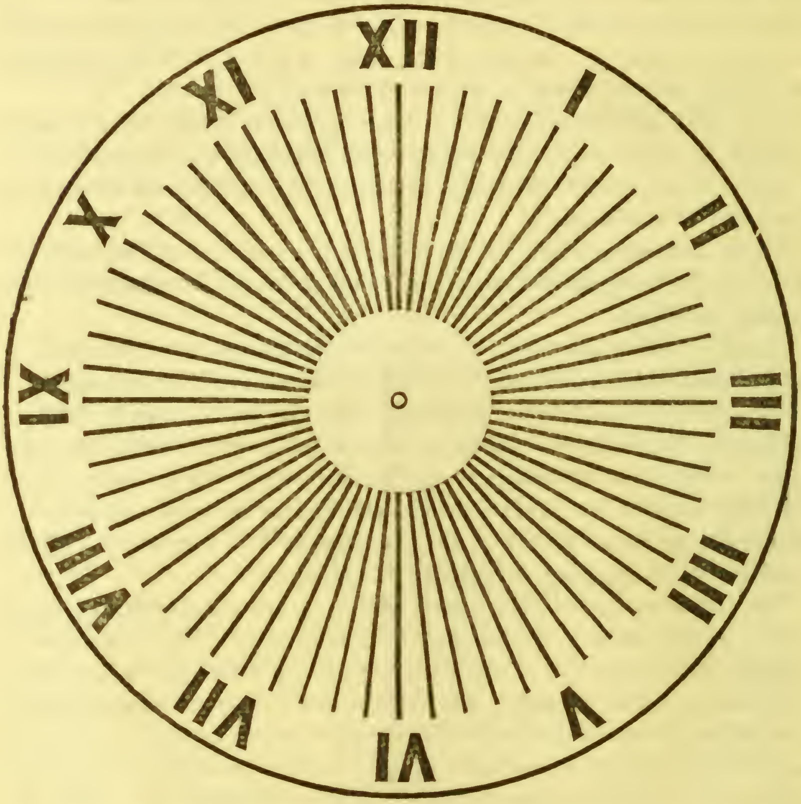


Fig. 2.

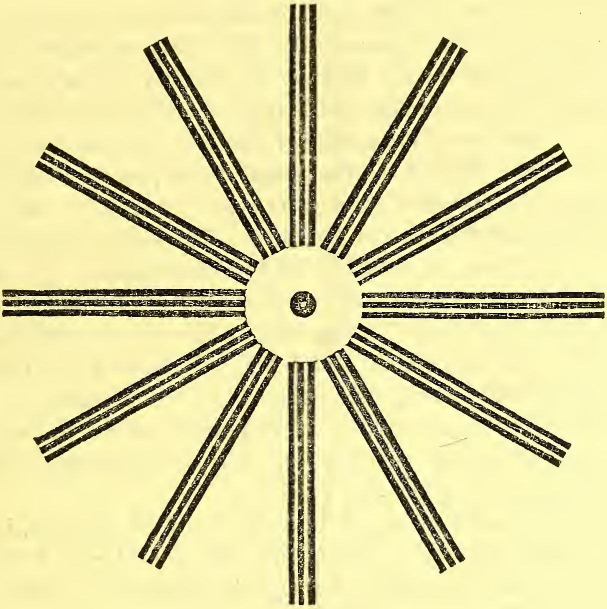
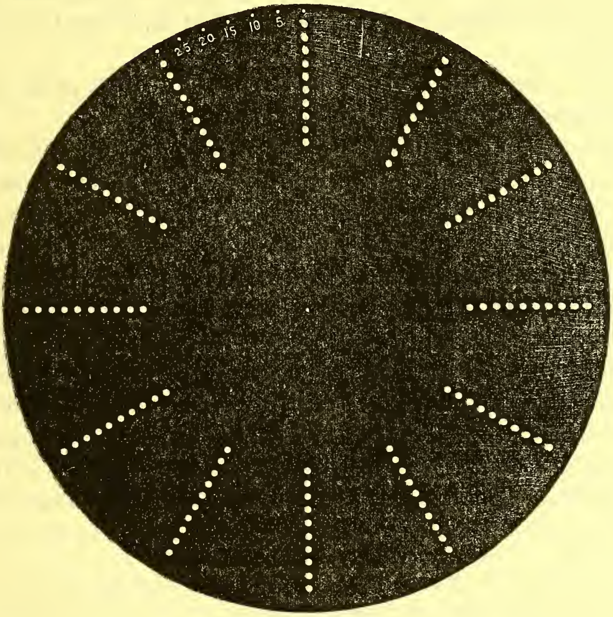


Fig. 3.



centre of the first.[1] These cards are about nine and a half inches in diameter.

[1] This use of the clock dial, for which I am indebted to Javal, who has employed it in his very ingenious optometer, has the important advantage over all other

The test-dots are arranged in from twelve to sixty radiating rows upon a circular card, similar to those used for the line tests, but are printed to show white upon a black ground (Fig. 3). They may also be punched through the card which may be hung in a window, with a background of thin paper. Upon a second card is printed a single row of dots similar to the first. These cards are arranged also to turn upon the pivot in the centre of the dial. If used as transparent objects, any desired inclination may be given by suspending them from one or another of the pin-holes figured near the circumference of the circle. The size of the dots or holes is, within certain limits, a matter of but little consequence. In cards with twelve radiating rows, I have made them about $\frac{1}{4}$ or $\frac{1}{8}$ of an inch in diameter; with sixty rows, about $\frac{1}{14}$ of an inch. These sizes correspond pretty nearly to Nos. LXX., XXXV., and XX. of Snellen's test-types. For smaller transparent test-objects, designed to be mounted in a lamp-screen, I have used the common perforated card-board of the shops, with holes about $\frac{1}{32}$ of an inch in diameter. The spaces between the dots I have made equal to the diameter of the dots.

These two kinds of tests may be usefully employed together, being in a certain way supplementary to each other. They enable us to determine independently, and with great accuracy, the direction of both principal meridians, and each may be made to serve in many ways to control and correct the results obtained by the other. They afford, also, a ready means of detecting any irregular astigmatism dependent on corneal or lenticular malformation.

Smaller test-diagrams, of about one-third the size of those described, are useful in the examination of strongly myopic eyes.

In applying these tests to the investigation of a case of possible ametropia, with or without astigmatism, one eye is to be excluded from participation in the visual act, either by the use of the little screen attached to the spectacle-frame, or by partially covering the eye with a card or book. The eye under examination is then directed to the diagram with the twelve radiating triple lines (Fig. 2), hung upon the opposite wall of the room.[1] The question may then be asked, whether any one of the twelve sets of lines is distinctly seen. The eye is then to be corrected, if necessary, by the weakest concave or strongest convex glass compatible with perfect vision of any one set of lines. Should all the sets of lines appear equally distinct during the trials with different glasses, and especially if the same result is obtained with the test-dots, we may confidently decide that the case is not one of astigmatism, and may proceed at once to the determina-

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graduations of the circle, that it is one with which everybody is familiar. The first diagrams which I drew were made with thirty-two divisions, named after the thirty-two points of the mariner's compass.

[1] If the eye is strongly myopic, it may be more convenient to use a smaller test-object, which may be attached by a slide to a yard-stick, so as to form a sort of optometer.

tion of the acuteness of vision and accommodative range by the well-known method of Snellen. If, on the other hand, either with or without a correcting glass, the lines in one meridian are more distinct than in others, we may be sure that we have to do with a case of astigmatism. The direction of this meridian of most distinct vision is now to be carefully determined by the diagram with the sixty radiating lines (Fig. 1). To ascertain with greater accuracy the refractive power of the eye for this meridian, the card with the three parallel lines may now be placed upon the pivot, and turned in the direction of most distinct vision, as determined by the last observation. A few trials with stronger or weaker glasses will soon determine the proper correction for this meridian, which, if the examination has been properly conducted so far, will be the measure of any refractive anomaly in the ocular meridian of the least refraction. It only remains to determine the refractive power of the eye for the other principal meridian, which may be done by the use of common concave glasses in a stenopæic apparatus, or, still better, by the use of concave cylindrical glasses. The card last used is to be turned to a position at a right angle to the first, and concave cylindrical glasses, with their axes in the same direction, held successively before the eye until the lines appear as distinct as they appeared in the other meridian; if the stenopæic apparatus, with common concave glasses, is employed, the slit must be turned at a right angle to the direction of the test-lines. Having thus ascertained the weakest glass through which the three parallel lines are distinctly seen in the last position, we have in the focal distance of this glass the measure of the difference of refraction in the two principal meridians, or the degree of the astigmatism; the absolute refractive power of the eye in this meridian is found by adding this value to that already found for the other if the eye is myopic, or by subtracting it if hypermetropic.

Having thus determined the refractive power of the eye in the two principal meridians, it is well to test the result by means of a trial-glass, made either by the combination of two cylindrical glasses adapted to the different degrees of refraction in the two meridians, or by an equivalent combination of a spherical with a cylindrical lens.

The other eye is then to be tested in precisely the same way as the first, and the result controlled in the same manner.

Having thus fitted the two eyes with experimental glasses, they should be tried together in binocular vision, using all or any of the test-diagrams, the final test being always the equal and uniform distinctness of all the lines or dots in all parts of the diagram.

If any presbyopia or accommodative insufficiency is present, it may now be estimated by placing a pair of convex glasses, fitted in a frame as a temporary eye-glass, in front of the trial-spectacles, and testing with the smaller types of Jaeger or Snellen.

These test-diagrams may be variously modified in form, and with advantage, for it often happens that a person not accustomed to analyze his

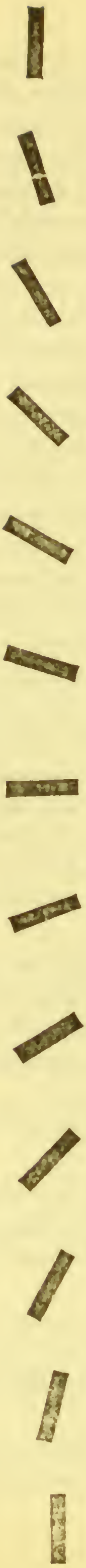
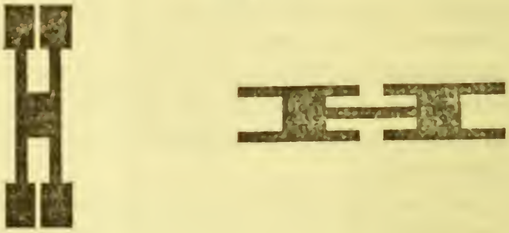


Fig. 4.

visual perceptions may fail to appreciate a defect which a second observation, made upon another diagram, may reveal. Thus the meridian of most distinct perception of the lines in Figs. 1 and 2 is the opposite of that in which the dots in Fig. 3 appear most distinct one from another. By arranging the same test, too, in different ways, it is possible to ask the same question several times in succession without seeming to do so. For reasons of this nature, as well as to provide a good test for astigmatism more exactly comparable with Snellen's test-types, I have arranged a diagram (Fig. 4) in which short lines or sets of parallel lines of successively increasing degrees of inclination are placed in a linear series, instead of in the form of radii of a circle.

Test-letters may also be employed, with a certain advantage, in the detection of astigmatism. Thus a letter from one of the larger series of Snellen—as No. XXX.—may be repeated several times, always of the same superficial area, but varied in the proportion of height to width (Fig. 5). These letters, which are of common use in ornamental printing, under the names of condensed and expanded letters, are seen by an astigmatic person with very different degrees of distinctness, that particular letter always appearing the clearest whose long diameter corresponds most nearly with the direction of the meridian in which the line tests are most distinct.

Fig. 5.



These short test-lines, and expanded and condensed letters, serve also to illustrate the different degrees in which the legibility of different styles and kinds of letters is affected by astigmatism. Thus the capital Roman letters are not properly comparable with the small letters, and still less with the large or small Italics. Neither ought Roman letters to be compared with writing characters, or with German, Greek, or Oriental texts. Much depends, too, upon the proper spacing of the letters in the lines, as well as of the lines themselves, for the same astigmatic eye may, with different degrees of accommodative action, be troubled either by an apparent running together of the letters, or by confusion of the lines.

Test-letters for determining the acuteness of vision should be constructed, therefore, not only of sizes proportionate to the distances at which they are designed to be used, but also in such a manner as neither to exaggerate nor conceal the visual defects due to astigmatism. To this end they should be made up, so far as may be, in about equal proportions of vertical and horizontal lines of uniform thickness. Each letter, too, should be, as nearly as is consistent with good proportion, of equal height and width, and the spaces, both between the letters and the lines, should be proportionate to the size of the letters. These conditions were first realized by Snellen, in his "Letterproeven," or "Test-types," published in Utrecht in 1862, and now almost universally adopted as the standard of visual comparison. It is possible, however, that the very simple "Gothic" form of letter **TH** may be preferable to the somewhat more complex "Antique" letter **TH** adopted by Snellen; the experiment has been partially tried in a recent work by Dr. Williams, of Boston (*Recent Advances in Ophthalmic Science*, Boston, 1866).

St. Louis, October, 1866.